Appendix 3-3

Hydraulic Simulation Methods

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Gas hydraulic simulations were completed for the various pipeline scenarios to determine the number of compressor stations required for prescribed flow rates and the fuel consumption at these stations. Capital and operating costs for the stations were estimated based on the simulation results, combined with the capital and operating costs for the pipeline and used to determine COS as a function of gas flow rate.

A gas hydraulic simulation was completed for each unique pair of COS and gas flow values used to construct the J-curves. The hydraulic simulations were completed using an in-house gas hydraulic model that integrated pipeline alignment data with process simulation software and a ROI economic model.

Integration with HYSYS Process Simulation Software

HYSYS is an industry standard process simulation software package produced by Aspen Technology. The gas hydraulic model consists of pipeline alignment and gas compressor data in MicroSoft Excel spreadsheets linked with HYSYS via macro program code. The macros are used to simulated pipeline and compressor station operation by running unit operations configured in HYSYS using input from the Excel spreadsheets. Results are extracted from the HYSYS unit operations and recorded in the Excel spreadsheet. All information regarding an input and output from a hydraulic run are contained in the spreadsheets.

The HYSYS unit operations used to simulate a gas compressor with propane refrigeration of the discharge gas are shown in **Error! Reference source not found.**. The HYSYS unit operations determine physical properties of the flowing gas based on operating conditions and the gas composition. Controls and methods required to simulate the propane refrigerant system are set within HYSYS.

Various industry standard flow equations exist for calculating pressure drop of gas flowing through a pipeline. These equations are based on the same basic flow equation, but address friction factors differentially depending on the type of flow being modeled. For example, one equation may estimate friction factors based on calculations specific to large diameter pipelines operating at high pressure while another equation is specific for smaller diameter pipelines operating at low pressures.

A wide range of flow regimes were modeled for the J-curve analysis. The HYSYS pipe segment unit operation uses as single flow equation and calculation method for estimating friction factors. Use of a single flow modeling method is sufficient for the purpose of J-curve analysis, however, modeling methods should be reviewed during future design efforts with regard to their applicability to the selected gas flow scenario(s).

Assignment of Compressor Stations

Compressor stations were placed along the pipeline according to most restrictive of the following criteria:

based on compressor horsepower,

minimum allowable operating pressure,

maximum allowable gas velocity through the pipeline,

potential to overpressure the pipeline at downstream locations.

The criteria governing the location of each compressor station is identified in the simulation output.

Placement based on compressor horsepower

Four sizes of gas compressor sets were evaluated in the hydraulic simulations (Appendix C). The HYSYS compressor unit operation was run based on the gas conditions at that point to determine if a compressor should be located at this location. The maximum discharge pressure based on the site rated horsepower available to the particular gas compressor was determined and compared to the pipeline MAOP. If the maximum pressure was less than MAOP, then a compressor was assigned to the pipeline node immediately upstream. The upstream node was used to ensure that the station would return the gas pressure to MAOP and provide the maximum flow efficiency downstream.

Certain locations in rough terrain or next to population centers were restricted from consideration for location of compressor stations. If a station needed to be assigned within a restricted area, the station was moved either to either upstream or downstream of the area depending upon the circumstances.

The site rate horsepower available at the shaft of the gas compressor was determined by adjusting the ISO rated horsepower as follows:

a. Interpolate the turbine horsepower as a function of ambient air temperature from performance curves provided by the manufacturer;

b. Adjust the turbine horsepower for elevation based on general de-ration curves (reference: Engineering Data Book published by the Gas Processing Suppliers Association)

c. Apply de-ration of 0.984 assuming a turbine inlet pressure loss of 4" of water;

d. Apply de-ration of 0.9965 assuming a turbine exhaust pressure loss of 2" of water;

e. Apply de-ration of 0.96 for non-recoverable power losses due to aging;

f. Apply de-ration of 0.96 for recoverable turbine power loss between cleanings;

g. Assume no gear box losses between turbine and gas compressor

The maximum discharge pressure based on site rated horsepower was reduced by pressure drop through the station discharge piping and any refrigeration of cooling to yield the station discharge pressure. The station discharge pressure was compared to MAOP for locating the station.

Placement based on minimum allowable operating pressure

It was assumed that compressor station fuel would be extracted from the pipeline gas. Stations were assigned to maintain a minimum pipeline operating pressure of 500 psig in order to provide fuel source at a pressure above that of the turbine fuel system. The minimum allowable pipeline pressure was adjusted upwards for simulation of pipelines transporting an enriched gas in the dense phase in order to avoid the two-phase region.

The minimum operating pressure of 500 psig was used for all simulations of pipeline transporting utility grade gas. A minimum allowable operating pressure of 500 psig was used for all runs regardless of whether the pipeline was transporting hydrocarbon dry gas or an enriched gas. Whenever a pipeline operating pressure below the specified minimum was encountered, a compressor was assigned at the next upstream node. If the upstream node was restricted for location of a station, then the station was moved further upstream to the next unrestricted node.

Placement based on maximum velocity

API Recommended Practice 14E titled "Recommended Practice for Design and Installation of Offshore Production Platform Pipeline Systems" contains recommendations regarding the maximum velocity of flow through a pipeline. The code recommends a procedure for establishing an "erosional velocity" where no specific information as to the erosive/corrosive properties of the fluid is available. For solids-free fluids, it is recommended that the following formula be used:

Fluid erosional velocity in feet per second = 100 / (fluid density in lbs/ft3) ^ 0.5

It is stated in the API code that velocity may be a noise problem it exceeds 60 feet/second; however, the velocity of 60 feet/second should not be interpreted as an absolute criteria.

The natural gas transported via the spur line will likely be free of solids and water, thus little internal pipe corrosion should be encountered. Although potentially conservative, the above fluid erosional velocity was used to determine the maximum allowable flowing velocity of gas within the spur line. The maximum allowable velocity was limited to 55 feet/second to avoid any potential issues regarding noise.

Comment [CG1]: Erosional or errosional ?

Whenever a gas velocity above the maximum allowable was encountered, a compressor was assigned at the next upstream node. If the upstream node was restricted for location of a station, then the station was moved further upstream to the next unrestricted node.

Placement due to potential overpressure

Due to the weight of a dense phase gas, assignment of a station at location with a relatively high elevation may result in pressures above MAOP at lower elevations downstream (Section **Error! Reference source not found.**). In such circumstances, the discharge pressure of the station must be reduced in order to prevent over pressurization downstream or the station assigned further downstream. Reducing the discharge pressure underutilized the available compression horsepower. Assigning the station to a location further downstream will result in full utilization of the compressor horsepower without over pressuring the pipeline at downstream locations.

Whenever possible, stations were moved to downstream locations to avoid pipeline over pressurization. Stations were not moved downstream if such reassignment would be in areas within which stations were restricted for assignment.

Flow rate adjustment

Compressor stations were assigned for a given gas flow rate based on local conditions along the pipeline without regard for conditions at the pipeline terminus. Station assignment could result in a pipeline outlet pressure well above the desired target value. Such scenario would represent underutilization of the installed horsepower because the flow could be increased until the discharge dropped to the target.

It is important that common conditions at the pipeline terminus be achieved for all hydraulic simulations in order to avoid bias in the J-curve analysis. The J-curves are plots of COS versus flow rate. Use of a flow rate that underutilized the installed capital for compression would bias the resulting COS upward.

The flow through the pipeline system was adjusted until the pressure at the pipeline terminus was within 50 psi of a prescribed value. The location of the stations were reassigned a based on the local criteria described in the previous section. The pipeline flow was adjusted to ensure that temperature of the gas at the pipeline terminus was no more than 2.5 degrees F below a 15 degree F target and that the gas velocity did not exceed the erosional velocity by more than 2.5 feet/second. The flow through the pipeline was governed by the most conservative of the three criteria.

Pipeline Fuel Consumption

Fuel consumption was determined by calculating the operating horsepower of the compressor turbine driver and then applying a heat rate appropriate for the particular turbine. The heat rate for the Solar brand turbine drivers for the compressors adjusted for temperature and interpolated from manufacturer operating curves. The heat rate of the turbines for the refrigerant compressors was assumed to be the same as that of the smallest Solar turbine generator set unadjusted for site conditions.

Fuel consumption for pipeline gas heaters was determined based on the heater load and an 80% overall heater efficiency based on the lower heating value of the fuel.

The total fuel consumption for the station was the sum of the individual fuel usage of the gas compressors, refrigerant compressors, and gas heaters. In all cases, fuel consumption was based on the lower heating value of the fuel.